ANCIENT ALPINE GLACIERS OF THE SIERRA COSTA MOUNTAINS IN CALIFORNIA

INTRODUCTION

Northwestern California is a vast complex of mountains, forming the Klamath system, whose geological features are similar to those of the Sierra Nevada range. Centrally situated within it is a series of high granitic and syenitic peaks, constituting the range of the Sierra Costa Mountains. Beginning in Castle Crag, about fifteen miles southwest of the lofty volcanic peak of Mt. Shasta, they trend thence southwestward about fifty miles, with an average width of between fifteen and twenty miles. Within this territory of eight or nine hundred square miles there are a score or more of bare, ragged peaks rising to altitudes of 7200 to 9345 feet above the sea. Between them are deep, narrow valleys whose floors have altitudes between 2500 and 6500 feet, averaging about 4000 feet. Some of the more elevated of these present distinct evidences of past glaciation. The glaciers were very localized in development, never coalescing to form a general glaciation of any part of the territory, and hence the glacial phenomena displayed in these mountain valleys are characteristically different from those of the drift-covered regions of the Mississippi basin.

GENERAL DESCRIPTION OF THE GLACIAL PHENOMENA

There is a radical difference in topography between the glaciated and non-glaciated valleys. The latter are V-shaped gulches with steep straight slopes and a width at the bottom often but little greater than that of the stream flowing within them. In places they are very rocky, with jagged ledges projecting from their sides. All the stony material found on their slopes is of the rock species underlying the soil on each particular slope. The same valley, traced up to where it once possessed a glacier, will rather abruptly change its form to a broad and

open U-shaped trough, with smooth and curved slopes, and a gently rounded floor. This change has been effected by a grinding away of the talus material and solid rock along the middle levels of the slopes and a filling of the extremely narrow lower portion of the gulch. The ravines have been destroyed, partly by filling and partly by the grinding away of the intervening ledges. Often this smoothing of the contours has extended up to a certain level, above which the mountain sides are deeply scored with ravines, and jagged with outcropping ledges.

Most of the valleys present but a moderate amount of ground-moraine, altho the lateral moraines are well developed. The glaciated slopes are abundantly supplied with bowlders of all the rock species occurring from thence to the head of the valley. They are embedded in a loose agglomeration of subangular gravel, sand and a little clay, forming a deposit quite unlike the till of the Mississippi basin, altho somewhat more nearly resembling the very stony moraines of New England. These lateral moraines are smooth in outline, rarely displaying a hummocky topography, and only in a few cases standing out distinct from the mountain ridges. In the unglaciated gulches, especially where the country rock is serpentine, extensive land slips are resting on the lower slopes, and they present a hummocky topography almost identical with that so characteristic of glacial moraines in the Mississippi basin, even to the extent of possessing kettle-holes containing lakelets. These must not be confounded with the lateral moraines.

Lines of erratics perched high on the mountain sides sometimes indicate the maximum altitude of the glacial action. From the smooth curved slopes of the lateral moraines, low narrow ridges of very stony material trend obliquely toward the center of the valley, those on opposite sides forming a loop, pointed downward. Sometimes they coalesce and are then cut by a small canyon-shaped valley thru which the stream finds an outlet from the enclosed basin above. These are the only representatives of true terminal moraines (being formed at successive

stages of readvance during the general recession of the glacier), but are quite insignificant as compared with the lateral moraines.

Near the heads of the glaciated valleys the rock surface is often bare over thousands of square feet, and is then seen to be smoothed and rounded by the grinding action of the ice. Some distinct grooves appear, but are not common. Of more frequent occurrence are fine lines or striæ, altho where long exposed these have been destroyed by weathering.

By far the most characteristic of the glacial phenomena of the Sierra Costa Mountains are the high meadows and lakelets. The former are smooth expanses of the valley floor a mile or more in length by half as great width, occurring near the heads of the valleys. They are inclined to be damp and boggy, and are grassed, instead of timbered and brushy, as other portions of the mountain region. They are underlaid with a fine gravelly silty ground moraine, and over their surfaces are frequently scattered large erratics of an englacial and superglacial mode of transportation. The lakelets are rounded bodies of clear cold water, varying from a fraction of an acre to twenty or more acres in extent, sometimes occupying rock-bound basins of glacial origin, but generally held in behind moraines. Around the border may be a tiny beach of white sand, or a narrow strip of flat, grassy land composed of black peaty soil. Some of these tiny mountain tarns are perched high up on the mountain sides in small coves or niches abraded from the solid rock by the downward pressure of the ice under the *névés*. A few of these coves are hundreds of feet in depth, have steep, often precipitous, rock-walls, and are nearly closed in by the surrounding ridges so that they closely resemble the *cirques* of the Alps.

An especially favorable situation for the glacial lakelets is at the foot of high rock precipices which usually occur on the southern or western sides of the valleys. The glaciers invariably hugged the shady side of the valleys and there accomplished their most active grinding work. It was on the northern side of the frowning peaks that the ice laid longest, and when its final melting

was accomplished, depressions were left at the foot of the precipices which had been produced by the removal of the talus material and some of the solid rock. In several cases one may stand on a high peak and throw a stone so that it will drop into the clear water of a lakelet, 1000 feet below. These high precipices are another characteristic of the glaciated valleys, for they never occur elsewhere in these California mountains.

The glaciers headed in valleys whose altitude is now between 6500 and 7500 feet above the sea, and descended to 5000 or 5500 feet (with two notable exceptions). Thus the declivity of the glaciated valleys is great; but the descent is effected by a series of terraces or steps, gentle slopes alternating with steep, almost precipitous, sections where the valley floor is rapidly let down 100, 200 or even as much as 500 feet vertically. These "steps" are only in small part due to moraines, being composed mainly of solid rock. Over them the glaciers cascaded, forming extensive crevasses, then coalescing into a solid mass and moving along smoothly a mile or more to the next cascade. Toward the close of the ice period, when the main glaciers had shrunk to insignificant remnants, tiny glaciers continued to issue from under the local *névés* in the coves high up on the mountain sides, and cascaded over precipices as much as 500 feet in height.

I have mentioned a sufficient number of the features of these valleys to place it beyond doubt that they have suffered glaciation in some past period, and to demonstrate that the glacial action was essentially identical in character with that at present obtaining in the high Alpine valleys of Switzerland.

CHARACTERISTIC FEATURES OF INDIVIDUAL GLACIERS

The Castle Creek glacier — At its maximum extension, this glacier had a length of about two miles, a width of one quarter to one half mile and a depth of 500 to 800 feet. It was situated at the northern foot of Tamarack peak, near the junction between Trinity, Shasta and Siskiyou counties. The present altitude is about 6500 feet. Within the limits of its site are six pretty lakelets, one lying at the foot of a 1000-foot precipice. The glacier

flowed in an easterly direction and hugged the southern side of the valley, there leaving the rock bare of talus or morainic material. In receding, it melted away from the warm northern side of the valley, and left several successive lateral moraines on the valley floor, running lengthwise of it. The last of the series is about in the center. A trough shaped depression occupying the southern half of the valley indicates the final track of the dying glacier. In it lie some of the lakelets. A tributary glacier entered the main trunk at nearly a right angle, and cascaded over a rock-ledge now 500 feet above the main valley floor. The ledge is smoothed and striated. Above it a lakelet is held behind a moraine composed of clay, sand, gravel and bowlders, some of which are beautifully striated. The interesting feature of this glacier was its evident sensibility to the sun, causing it to melt away from the sunny side of the valley long before it disappeared from within the shadow of Tamarack peak.

The Salmon River glacier.—This was seven miles in length, one half to one mile in width and 1000 to 1500 feet in depth. Its course was a little east of north. It headed at about 6500 feet of altitude (present), and descended but little below 5500 feet. On the west of its upper half was the high granite peak of Mt. Courtney, whose slope is now bare of loose rocks and soil from summit to base and is worn smooth and rounded by glacial abrasion. From the precipitous pinnacles of the sawlike crest, huge bowlders of granite crashed down upon the ice, and now lie scattered upon the floor of the valley and even over the opposite slope. Several are as large as an average miner's cabin. Beyond the granite of Mt. Courtney, where the rocks are mainly hornblende and mica schists, the upper limit of the glacier is clearly defined high on the mountain sides by a sharp line below which granite bowlders are numerous and above which there are none; also, by shoulders or small precipices on the inter-ravine spurs of the mountain on the east, showing to what height the glacial abrasion extended.

Many prospectors and semi-scientific observers have noted the fact that the upper four or five miles of the original main

Coffee Creek has been beheaded and added to the South Fork of Salmon River, but not many have clearly discerned that this was due to glacial action. In ascending the Upper Coffee Creek valley, after the great bend is passed, the floor widens to quite a plain, there being here a heavy filling of waterlaid gravel and sand, the extra-glacial deposit of the glacier above; on this, at the mouth of each tributary gulch, there is a beautiful alluvial fan. About one and one half miles below the head of the creek, a slight ridge crossing the valley and carrying granite erratics marks the extreme limit of the glacier. From here to the summit stretches the "Big Flat," a smooth plain of fine gravel and sand (with scattered granite erratics) about one and one half miles in length and one half mile in width. At its upper end (which is the summit of the Sierra Costa Mountains, the water-parting between the main Klamath and the Trinity River systems, and the Trinity-Siskiyou county line) there is the slightest tendency to a morainic character. This "Big Flat" has an altitude of 5500 feet while the mountains on either hand rise to 7000 and 7500 feet. Here the glacier made a filling several hundred feet in thickness, thus obstructing the valley. At the same time it wore the rock wall of the valley on the west (which had already been nearly cut thru by the head water erosion of the original South Fork of Salmon River) so thin that a glacial stream crossed the ridge in a col and soon cut down a gorge. Hence it is that the South Fork of Salmon River rises in the head of the original Coffee Creek valley, follows it for four or five miles until within a few hundred yards of the present head of Coffee Creek, then turns to the west at a right angle, and passing out of the broad valley thru a narrow gorge where it abounds in rapids and falls, it makes its way thru unglaciated gulches to the Klamath. This is one of the finest examples of the beheading of a stream by glacial action that I know of.

As indicated by the granite erratics, the surface of this Salmon River glacier descended 1000 feet (and the glacier thinned to that amount) in the last one and one half miles of its course.

Within several miles of its head, the South Fork of the Salmon River has carved a pretty postglacial gorge or tiny canyon in the solid rock of the old valley floor. This is twenty to thirty feet in depth, has precipitous walls, and is no wider than the small stream flowing in it. It abounds in rapids and low cascades.

The Union Creek glacier.—This occupied the next main series of high valleys to the east of the Salmon River glacier. There was a main trunk five miles in length, and two branches each several miles in length. The width was one quarter to one half mile, and the thickness of all approximated 1000 feet. They headed at about 6500 feet (present altitude), and the main trunk descended to 5000 feet of altitude. Near its end it was much contracted, and but little modified the original V shape of the valley. Its extent is clearly defined by its very bowldery lateral moraines. One of these partly obstructs the mouth of a tributary valley, that of Pin Creek, which was not glaciated, altho equally as elevated as glacier occupied valleys on either side of it. This was because it opened too directly toward the sun.

When recession had proceeded to the extent of dissevering the branches of the glacier in the East and West Union Valleys, that of the East Union was the most vigorous, and formed a beautiful half-looped terminal moraine at the junction. The West Union Creek flows swiftly in a shallow ditch cut into the very bowldery deposit just outside of the crest of the moraine, but transverse to the general slope of the surface. This shows that this creek occupied its present course as early as the time when the moraine limited the East Union glacier. The extremely small amount of erosion accomplished on this steep declivity tells of the recency of the glacial epoch in these mountains.

The three Unions have the usual meadows, and are well supplied with glacial lakelets.

The Swift Creek glacier.—The characteristic features of this member of the glacial series were its length, its descent to a low

altitude, its heavy ground moraine, and its beautiful terminal moraine.

At its maximum extension, this glacier had a length of not less than fifteen miles, a width of one half to one mile, and a depth of 1000 to 1500 feet. It was the largest single mass of ice, so far as I know, of the Sierra Costa Mountains. It headed among the peaks in the highest portion of this range, at an altitude now about 6500 feet, trended in an easterly direction, forming the broad flat of the Mumford meadows (altitude 5500 feet), then ran southeasterly, descending rapidly to a level now little more than 3500 feet above the sea, where at ten miles from its head, it suddenly issued from the high mountains, and turning to the northeast, it deployed upon and across a broad basin valley of Miocene age and later, and terminated very close to the site of the Redding and Trinity Centre road at an elevation now no greater than 2500 feet above the sea. Here are, so far as I am aware, the least elevated direct glacial deposits west of the Sacramento River, if not in the whole state of California.

Among the prospectors of northern California, the "cemented gravel of Swift Creek" is a term to conjure with. It is essentially non-gold-bearing, and so far as the ability of the average miner to sink a shaft through it is concerned, it is bottomless. It is an unstratified agglomeration of bowlders, cobbles, pebbles, sand, silt, and clay, which occupies the valley from head to mouth, forms the flats or meadows, and is trenched by a narrow canyon carved by Swift Creek in postglacial time. Where the stream, in undermining a bank, has made a recent excavation, the deposit has an extremely fresh appearance and a delicate light bluish tint. Many of the included bowlders are rounded and polished, and not a few are beautifully striated. It is as typical a till as any to be found on this continent. Being largely the result of glacial abrasion on the rock floor and walls of the valley (serpentine mainly), it is slightly cemented by the large constituent of unoxidized magnesian and calcareous salts. Most of the included rock fragments are serpentine of the black

amorphose variety, and the light oil-green schistose variety, and the blue tinting was derived from the grinding of this formation. It cannot be worked for its included gold as a placer deposit, because there has been no concentration of the precious metal by water action as in ordinary stream alluvium.

This fine deposit of subglacial till or ground moraine attains its fullest development about midway of the course of the glacier where it must have a depth in places of not less than several hundred feet. At an altitude of about 5000 feet, the most prominent glacial features cease. Beyond this the valley contracts and descends rapidly over a series of high steps, which are strewn with a profusion of bowlders, some of which are striated. Everything here is confusion — there may be indistinct terminal moraines, lateral ridges, *roches moutones*, and some ground moraine, but the best expert cannot get much regularity out of the piles of bowlders heterogeneously distributed along the slopes of the bounding mountains and on the irregular valley floor. Here the creek descends rapidly in one long series of rapids and cascades, along its bowlder strewn bed, and in one place has cut a beautiful gorge thru the solid serpentine rock. It is several hundred feet in length and thirty to fifty feet in depth, and no wider than the stream. With its perpendicular and even overhanging walls, it is a veritable canyon. It abounds in *remolinos* (pot-holes) whose mode of formation can plainly be seen, from the clearness of the water.

When the Swift Creek glacier issued from the deep valley in the high Sierra Costa Mountains and deployed across the Miocene basin, it did not spread out as an alluvial delta, but it maintained its narrowness to the end, five miles distant. Around this extra-montane portion it formed a beautiful moraine. The constitution of this is essentially similar to that of the cemented gravel farther up the creek, except that it contains less clay, is looser and coarser in texture, and has some large erratics on its surface. Where trenched by tributary creeks and its interior freshly exposed, polished and striated pebbles and bowlders are not difficult to find. Two parallel ridges of about equal height,

and even crests, trend from the sides of the mouth of the upper valley northeastwardly across the Miocene basin, gradually descending toward Trinity River. Between them is a flat-bottomed, steep sided depressed area, 300 to 500 feet in depth and one half mile in width, evidently representing the cross-section of the glacial tongue. From the crests of the ridges more gentle slopes of very bowldery land extend outward and gradually merge with the erosion surface. These ridges are the extra-montane extensions of the lateral moraine, but also contain ground moraine and may be considered a terminal moraine. Near the Trinity River they flatten down, become hummocky and indistinct, but appear to curve around the end of the site of the ancient glacier and connect, except for the postglacial canyon which the stream has cut thru the moraine. Beyond this is a fine example of a fan-shaped extra-glacial delta, which occupies several square miles in the valley of the Trinity River, and its outer edge descends almost to the level of that stream itself.

This glacial tongue reached the northern end of the low Minerva range of mountains, and built its moraine across the mouths of several of the gulches. These have been filled nearly to the level of the moraine summit by fine silts, and form extensive grassy flats composed of deep black soil free from pebbles. Along the moraine the flats have some large angular erratics on their surface; these have slidden from the surface of the glacier.

In the bottom of the depressed area within the moraine Swift Creek has eroded a canyon 75 to 150 feet deep and 300 to 500 feet wide, widening and shallowing toward the mouth. This seems large, but represents glacial as well postglacial stream erosion.

On the whole, the glacial features of the Swift Creek valley are extremely interesting and instructive, and, from its accessibility, should become classical among students of California Quaternary geology.

The East Fork glacier.—This occupied a high valley, steeply descending on the east face of Granite Peak, a few miles northwest of Minersville. Near its head a precipitous mountain side

shows the smoothing and rounding action of the glacier up to a certain height, above which the bare rock is extremely rough and jagged. Some glacial grooves are seen and a little striation. In another place there is a well-defined line of perched erratics.

This glacier also issued from the high mountains, and it cut directly thru the old Miocene river channel, carrying its huge granite bowlders nearly or quite to the Minersville-Trinity Centre road, terminating at a point probably now no greater than 3000 feet of altitude. It is a well-known fact that all the gulches which are cut into this old Miocene channel deposit have been rich in placer gold, except the valley of the East Fork, which cuts directly thru it, and yet never paid to work. The apparent anomaly is explained when it is understood that the East Fork glacier ground all of the gold-bearing alluvium out of the valley and left in its place its own only slightly auriferous deposit — the glaciated valleys are never worked as placers.

Quite a number of other valleys in the Sierra Costa Mountains were once occupied by glaciers. The presence of a number of lakes (as mapped) in the deep canyons south and east of Mt. Thompson of the granite Cariboo range seem to indicate that a cluster of them occupied that region. Probably a score or more existed in Trinity county alone; but the examples given in this paper are typical of them all, and will suffice for the purposes of the present study.

THE AGE OF THE GLACIERS

At one time I thought I had detected evidences of two glacial epochs in the Sierra Costa Mountains, one very recent and another much older, but I have had to revise this opinion. The deposits near the lower end of the glaciated valleys are of slightly more aged appearance than those near the heads, but the contrast is not great. They are essentially a unit, so far as age is concerned.

The weathering of the once striated, polished, and perfectly smoothed rock surface, the erosion of small canyons in the rock-floors of several of the glaciated valleys near their heads, and

the peaty accumulations about the borders and on the bottoms of the lakelets show that the glaciation has not just terminated — the ice has been completely gone for at least several thousand years. Yet the many lakelets held behind frail barriers of till, the cascades and rapids, and the generally uneroded condition of the drift tell, in unmistakable terms, of the comparative recency, geologically speaking, of the glaciation. Subaerial erosion, aside from one main stream channel in each valley, has been practically nothing. Even the excavation of the single central canyon was largely accomplished while the ice yet lingered in the heads of the valleys, and by its rapid melting greatly increased the streams. With the steep declivities and the heavy annual precipitation, it is remarkable how little erosion has been accomplished in northwestern California since the glacial epoch. Certain cemented river gravels in the valleys of the East Fork of Trinity River, the main Trinity River, and lower Coffee Creek, which represent the outflow from the glacier, rest upon the lowest bedrock in these valleys, and the canyons since excavated in them are quite insignificant. Glaciation was one of the very latest events in the northern California valleys. That it was of late Quaternary age requires no argument.

The beautiful sky-blue till of the Swift Creek valley has a freshness which may be likened unto that of the Wisconsin drift-sheet in the Mississippi basin, and oxidation of its surface portion has not proceeded to any greater depth. Indeed, the youthful appearance of the whole series of glacial phenomena is identical with that which has come to be associated in my mind with the Wisconsin drift sheet. I am certain that this Sierra Costa glaciation was not the age equivalent of the Iowan or any earlier drift sheet. I am equally as certain that the glaciers disappeared a sufficient length of time ago to carry the glaciation back to the Wisconsin epoch. If there were two Wisconsin glaciations in the Mississippi basin, as some glacialists seem inclined to conclude, this California glaciation represented the later. At any rate, the glaciers of the Sierra Costa Mountains certainly were of Wisconsin age.

DISCUSSION OF CLIMATIC CONDITIONS DURING GLACIATION

It goes without saying that it was cold and there was much snow. But under this heading I wish to argue that there was no difference in the *character* of the climate between that and now—merely a lowered annual temperature and probable increased snowfall. The present climate of the Sierra Costa Mountains partakes of the general equability of the Pacific Coast region, but in addition possesses a typical alpine character. A strong contrast between the heat of night and day, *and between that of light and shadow*, is a characteristic of high altitudes where the atmosphere is clear and light, and radiation rapid. One may suffer from the heat in toiling up a sunny slope, while the air in the shadow of a peak may seem almost freezing cold. This is the condition of today at the higher levels of the Sierra Costa Mountains, and the behavior of the glaciers indicates that the same obtained in their time. They were unusually sensitive to sunlight, and shrank into the shadow of the peaks.

Gulches which faced the sun were unglaciated, altho perhaps surrounded by others in which ice accumulated to a depth of over 1000 feet. In fact, shadow was as much one of the necessary conditions of glaciation as cold and snow fall. This shows that the climate possessed the same alpine character as today. I am strongly impressed that the evidence indicates an altitude for these mountains during the Wisconsin epoch, at least as great as the present.

A POSSIBLE CAUSE OF THE GLACIAL PERIOD IN THE SIERRA COSTA MOUNTAINS

I am not prepared to argue conclusively as to why these glaciers formed in the elevated valleys of the northwestern California mountains; but I wish to present, in closing this paper, what I conceive to be a possible explanation of their existence, an hypothesis sufficient to account for all their phenomena.

The valleys where the ice accumulated are all above 6000 feet of altitude, and the sites of the main *névés* approximate a general elevation of 6500 feet above the sea. Even today the

climatic conditions at this altitude are not far removed from those favoring glaciation. The winter snow fall on the mountains is heavy, they being near the coast. On the higher peaks, light flurries of snow are often seen in July, and by the end of October, the winter's snow has set in in earnest. Storm after storm ensues thruout the winter and well on into the spring. By April 1 it is no uncommon thing for the higher mountains to be sheeted under eight, ten, fifteen, or in places as much as twenty feet in depth of well-packed snow. This melts away slowly. By June, most of it is gone; by July, nearly all; but some remains all the year on the northern slopes of Mt. Thompson and Granite Peak and in sheltered ravines of Mt. Courtney. This perennial snow lies at altitudes of about 8000 feet.

Now, in my opinion, a general uplift of the entire region to the extent of 3000 feet would be a sufficient cause for the duplication of the ancient glaciers and a restoration of the whole mountain range to its condition in the Wisconsin epoch. That would carry the summits of all the peaks above 10,000 feet, elevate the main ones, such as Granite Peak and Mt. Courtney, to 11,000 and 11,500 feet, and Mt. Thompson would tower to the altitude of 12,345 feet, comparable with Mt. Shasta. The heads of the glaciated valleys would be elevated to 9500 feet. If perennial snow lies today in small ravines at 8000 feet, how readily must it have accumulated in deep valleys over 1500 feet higher and in the shadow of peaks towering to 11,000 and 12,000 feet. Considerable bodies of snow lie all the year at no greater altitude on the sunny side of Mt. Shasta, and one may see snow on any summer day by glancing at Lassen Peak whose altitude does not much exceed 10,000 feet. Both these mountains are far from the coast, in a comparatively dry belt.

From their nearness to the Pacific Ocean, the elevated Sierra Costa Mountains must have received a heavier snow fall at a given altitude than Mt. Shasta. Also, being a group of mountains (acting like an elevated plateau) instead of a single isolated peak must have favored a lowering of the temperature and increased precipitation. Even without an added snow fall, a

simple elevation would not fall far short of reproducing the glaciers. But as the result of the uplift, it is safe to count on a greatly increased precipitation. It appears to me evident that the present conservative estimated average for the higher regions of ten feet annually might be doubled. Of this amount one half, or ten feet in thickness, might melt from the surface of the *névés* during each summer (the sun finds difficulty in removing that amount even at present altitudes). The remaining ten feet might compact into one foot of ice. Were there no loss by outflow and melting at the end of the glacier, the accumulation of one foot of ice annually would reproduce the large Salmon River glacier in 1500 years.

But a large part of the ice moved outward beyond the zone of accumulation and was lost by melting. This loss was partly compensated for by heavy snow-slides from the surrounding precipitous peaks; yet, with the greatest latitude, we must allow two or even three times as great a period as that first mentioned for the accumulation of the glacier, and the attainment of its maximum extent. I consider 5000 years as a fair estimate, and one which is not too strongly open to criticism. By a lowering of the altitude to the present and consequent increased mildness of the climate (in other words, a restoration of present climatic conditions), probably about half that time or 2500 years would be sufficient to cause the disappearance of the glaciers, and give time for the repeated slight readvances which marked their recession.

The preceding is intended merely as a suggestion, a hypothesis worthy of serious consideration. The demonstration of its reliability will depend upon external evidence of the supposed temporary uplift of these mountains. This can only be secured by careful geological work between this range and the sea, which has not yet been done.

The importance to glacialists in general of studies on the localized Quaternary glaciers of limited mountain districts lies not so much in the contrast between their alpine features and the continental features of the great North American and

European ice sheets, as in the bearing which they may have on the fascinating and yet unsettled question of the "Cause of the Glacial Period." After trying unsuccessfully to solve the problem through a study of the varied series of drift sheets in the Mississippi basin, I have concluded that we will do well to take into account such evidence as may be gathered in alpine regions of glaciation — outlines of the main sheets, we may say — for here the problem of determining climatic changes is less obscure. The suspicion is growing in my mind that the "Glacial Period" in geology, as a glacial or relatively cold epoch of time, was of world wide extent in its effects, and the absolute determination of the cause of the past accumulation of glacial ice in one section will be the key to the solution of the problem of all terrestrial glaciations.

OSCAR H. HERSHEY.

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